

# Teachers from Instructors to Designers of Inquiry-based Science, Technology, Engineering, and Mathematics Education: How Effective Inquiry-based Science Education Implementation can result in Innovative Teachers and Students

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## ABSTRACT

There is a need for individuals in science, technology, engineering, and mathematics (STEM) careers to drive the innovation and research potential of Europe. Yet, there is expected to be a decrease in the number of STEM professionals, as there is less student interest in STEM fields of the study. Studies show that STEM classes that focus on inquiry-based science education (IBSE) are engaging and encourage students to become more fascinated with STEM fields. The Ark of Inquiry Project involves a consortium of STEM- and education-focused universities and organizations across Europe that created an online platform with IBSE and STEM lessons. The UNESCO Regional Bureau for Science and Culture in Europe conducted the pilot phase of the Ark of Inquiry Project in Italy from September 2015 to February 2016. In this paper, we will discuss some of the barriers to the expansion of this online STEM education project that was noted by the 14 participating Italian teachers of the pilot phase and 30 educators from India, Germany, Canada, and Denmark who participated through online surveys. We discovered that teachers must be able to overcome barriers of access to technology, misconceptions about women's abilities in STEM fields, and the effect of poor pre-service teacher training as it relates to implementing IBSE effectively for student-centered learning. This paper will focus on how the above factors hinder the growth of teachers as designers and facilitators of student-centered IBSE curriculum and will recommend how The Ark of Inquiry Project can be scaled up to impact the rest of the world.

**KEY WORDS:** inquiry-based science education; gender representation; technology; barriers; pre-service teacher training

## INTRODUCTION

Student interest in entering postsecondary science, technology, engineering, and mathematics (STEM) fields has declined in Europe, which means that there may be fewer STEM researchers in coming years (OECD, 2007). This decrease in researchers will impact Europe's capacity for quality research in science, technology, and engineering. The OECD-PISA report, 2015, suggests that, "at a time when science literacy is increasingly linked to economic growth and is necessary for finding solutions to complex social and environmental problems, all citizens, not just future scientists and engineers, need to be willing and able to confront science-related dilemmas" (OECD, 2015). This shows that innovation in STEM fields is imperative to the innovation potential of the world as society begins to face complex problems. These problems include the impacts of climate change, food insecurity, and explosive population growth. Therefore, the aim of the Ark of Inquiry: Inquiry awards for youth over Europe project (Ark of Inquiry) is to increase youths' interest in STEM careers by introducing engaging online inquiry-based science education (IBSE) activities at the elementary and

high school level, with a focus on responsible research and innovation (RRI).

The Ark of Inquiry Project is based on an online platform. The platform hosts STEM lessons and activities written by members of the Ark of Inquiry Project consortium or lessons acquired from partners or contributing educators. Teachers can search the platform's database to find and use appropriate IBSE activities for their classes.

However, the success of the project will be measured by the sustainability of the Ark of Inquiry online community, and how teachers continually engage with it to design meaningful IBSE learning experiences in their classrooms. Similarly, the project will be called successful if students learn about the inquiry process itself, as well as the STEM content being taught (Deliverable D2.1, 2014).

In this paper, we will primarily discuss the major roadblocks to changing the role of the teacher involved with the Ark of Inquiry Project from "instructor" of STEM content to "designer" of IBSE learning experiences.

From our research, we have observed that the following barriers to project success may include:

1. The inclusion of all students, more importantly girls, in STEM activities, especially when girls face stereotypes about their abilities.
2. The need for consistent and reliable access to technology by students and educators to take part in the online Ark of Inquiry Project. This includes teachers' capacity to use and manipulate new technology, and their potential to access new and relevant technology devices.
3. The lack of robust pre-service teacher training that discusses IBSE or educates teachers on how to effectively teach STEM content to their students in a way driven by real-world application and inquiry.

## LITERATURE REVIEW

### IBSE and RRI

Achievement studies demonstrate a link between enjoyment of learning science and science achievement. PISA 2006 showed that students' belief in whether they could handle tasks effectively and overcome difficulties was closely related to increased performance in sciences (OECD, 2007a). Research shows that IBSE lessons increase students' understanding and engagement with science (Pedaste et al., 2015). These IBSE activities are also intended to improve youths' inquiry skills, increase their awareness and understanding of conducting "real" science, and prepare them for addressing real-world STEM issues through a critical scientific process.

RRI is a framework that focuses on integrating European values, needs, and expectations into research practices. This framework is best outlined by the European Commission's RRI document: "RRI means that societal actors work together during the whole research and innovation process to better align both the process and its outcomes, with the values, needs, and expectations of European society" (European Commission, 2012). Therefore, students should learn STEM content that is based on real-world application.

Implementing RRI into the Ark of Inquiry activities and teaching includes discussing and debating scientific conclusions from research, which can be seen in the 5 inquiry phases followed by the Ark of Inquiry Project activities in the Appendix A (Pedaste et al., 2015).

### Attitudes toward Technology

According to the European Commission on Education and Training, there is an urgent need to boost digital and technology skills and competencies in Europe for the following reasons:

- 37% of the EU workforce was found to have low digital skills or none at all.
- Less than half of children are in highly digitally equipped schools and only 20–25% of them are taught by teachers who are confident in using technology in the classroom.
- Between 50% and 80% of students never use digital textbooks, or any other learning software in the classroom ("Opening up education through new technologies," 2017)

Therefore, the European Commission launched an action plan called "Opening up Education" in 2013. The main aim of this plan is to teach the digital skills to teachers so that they can deliver modern digital-based education. This OpenEdu framework contributes to the achievement of open and innovative education through digital technologies, which is one of the six new priority areas for the education and training 2020 in Europe. By increasing access to technology, young learners may learn more skills and be able to learn in digital spaces ("Action Plan for Education 2017," 2017).

A study on barriers to creativity and innovation across schooling in Europe indicated that tools such as textbooks are still the most utilized teaching resource in a class, closely followed by printed worksheets (Banaji et al., 2013). The authors of this study noted that while using these classroom tools were not barriers to creativity, the refusal of school leadership to go beyond these materials and use digital devices is a barrier to innovative classroom practices.

In addition, Banaji et al. noted that not all technology practices in schools are being implemented well; in some of the EU27 countries, experts reported that not all government or EU programs which require schools to buy interactive whiteboards (i.e., smart boards), laptops, tablets, or learning platform environments succeed in increasing students' technology and digital skills. If teachers do not know how to use the technology, the technology cannot be used effectively for new and innovative education purposes.

Furthermore, Banaji et al. also noted that due to insufficient teacher training, slow internet connections in schools, and a lack of leadership in the effective uptake of technology in schools, many of these technology implementation programs largely failed (2013). The presence of technology does not equate to digital and technological proficiency, just like the presence of a pen does not indicate a student's literacy level.

The researchers state that school administration, teachers, and school boards desire to control students' use of ICT at school. An example of this control is shown through schools' blacklisting of certain websites that the students cannot use as they are deemed "not educational." YouTube is a commonly blocked website because content creators on the platform are very popular with youth today. However, the platform also hosts STEM tutorials and demonstrations. By blocking these websites, students and teachers cannot think creatively about learning new information. The researchers note that these restrictions demonstrate an unwillingness of hierarchical systems in schools to be challenged.

According to a study done by the education foundation, the following key barriers to technology implementation in schools exist:

- Skills
- Access to technology
- Pedagogy
- Value for money, and

- Accountability (“Technology in Education: A System View,” 2014).

Basic online skills (to get online and navigate through websites), traditional IT skills (maintenance of IT hardware), computer science skills (understanding principles of information and computation), digital commerce skills, and data science skills are required for students to use ICT in a meaningful way.

There are major issues related to gaining quality access to internet and technology infrastructure in schools. Access can be even more difficult for small schools and schools in rural areas. Schools need to use the right blend of technology and teaching pedagogy to give students meaningful ICT education. Since access to ICT can be expensive and capital-intensive, schools need to look at innovative ways to fund and maintain these technological resources (“Technology in Education: A System View,” 2014).

### Gender Discrimination

There is ample research which shows that girls can be blocked from learning and participating in STEM classrooms due to stereotypes about their abilities based on gender. This is, especially, important to make note of in the context of this international education project. Different countries have varying social and cultural perceptions of traditional gender roles and can therefore hold prejudices against women pursuing STEM fields (Dweck, 2007).

Dweck describes two theories of intelligence that explains how individuals view themselves as learners (2007). The first theory is the entity theory of intelligence. If a learner holds this view, the learner believes that intelligence and ability are fixed and do not change over time; someone either is intelligent or is not intelligent. Dweck noted that the females she surveyed held this entity theory of intelligence. Therefore, the females in Dweck’s study were more vulnerable to losing confidence when faced with academic obstacles than male students (2007). Ultimately, Dweck found that this entity theory of intelligence could dissuade these female students from pursuing STEM fields (2007).

The second theory of intelligence is an incremental theory. If a student holds this view, they believe that intelligence and ability can be acquired through risk-taking, practice, and determination to learn. More males than females held this incremental theory of intelligence (Dweck, 2007). This capacity to take risks and make mistakes while learning is a fundamental part of IBSE during the questioning, experimenting, and investigation stages. Risk taking is also a fundamental behavior associated with academic success, especially relating to technology and mathematics (Ramos and Lambating, 1996). To include girls in STEM learning, Dweck recommends that a teacher should not focus on who has the scientific ability or who does not, but rather on how to foster and develop such abilities in students (2007).

This is also important to note when considering the “leaky pipeline” effect (Blickenstaff, 2005). The phenomenon is called the “leaky pipeline” because there is a disconnect between what the parents, teachers, and students believe that the female

students can do and what the hiring managers on the other side of the educational system believe the females graduates can do. The teachers and parents encourage girls to do and be whatever they want, but when they graduate from STEM university degrees, female graduates get fewer jobs than their male counterparts. This is where the pipeline becomes “leaky” because women graduate from STEM fields of study, and then, leaves when they cannot find the support, employment, or research positions (Blickenstaff, 2005). The pipeline provides female graduates, but hiring managers’ and supervisors’ misconceptions about their abilities because of their gender have stemmed the flow of women into STEM fields. These biases and misconceptions can include marital bias, or bias against women who may have children, among other things (Blickenstaff, 2005).

However, using examples of successful females in STEM, girls are more likely to enter STEM careers and overcome challenges (Blickenstaff, 2005). For example, women in undergraduate engineering degrees who read biographies of female engineers had more positive attitudes toward mathematics compared to women who read biographies of male engineers (Stout et al., 2011). Furthermore, telling women that STEM fields are becoming more diverse make them more likely to persist when they meet personal and professional challenges (Cheryan, 2012).

A large part of RRI is also ensuring gender balance in science research and education. This is because girls have been proven to be more interested in science education that is based on real-world problems (Sjøberg and Schreiner, 2010). For example, based on the science, mathematics, and technology education (SMT education) research by the relevance of science education project (ROSE project), girls were shown to be more oriented toward “values” when learning science content than boys (2010). Therefore, the ROSE project research demonstrated that girls preferred and excelled in activities focused on topics such as medicine and the environment, which put science concepts they learned into a meaningful context. Indeed, when discussing this finding, Sjøberg and Schreiner note that “one may well argue that the needs of our future society will be better served if potential scientists, engineers, and science teachers see the relevance of SMT to meet the pressing demands of our societies” (2010).

The UNESCO Regional Bureau is committed to achieving the Sustainability 2020 goals set by the UN; one of these goals is to achieve gender equality in work and in education (“Gender Equality and Women’s Empowerment,” n.d.). Since the Ark of Inquiry Project is an EU-funded science education project with a UN-umbrella organization as a consortium partner, this goal was a key focus during development of the materials used for teacher trainings in the pilot phase in all participating countries.

### Teacher Training

Of the key principles noted in the school policy document “Education and Training 2020,” very few policies are related to turning teachers from instructors to designers. The document does outline that a focus on ongoing professional development



is important and that stakeholders should collaborate to guide the preparation of teacher training courses. This will strengthen the capacity for teachers to move toward learner-oriented teaching and innovation in education (Working Group on Schools Policy, 2015).

IBSE focuses on the idea of the teacher as a “facilitator” in the classroom, rather than the sole “owner” of information (Pedaste et al., 2015). This means that students are encouraged to find their own information and ask questions, and the teacher needs to help them learn the research skills to find the answers. The ability of teachers to teach students the process of scientific research as well as the STEM content is imperative to the students’ innovation potential in the future, as students need to be able to solve problems with a robust scientific process. Therefore, the aforementioned ongoing professional development would be a good way to turn teachers from instructors to designers of IBSE learning experiences.

There is also an argument for the need to implement contemporary teaching and learning methods into science subjects; these new methods can help reduce the gap between the STEM knowledge gained in school and its application in the real world (Ault and Dodick, 2010).

According to the American Association for the Advancement of Science, over the past decade, there has been increased interest in inquiry playing a role in science education because it motivates students to learn STEM concepts (Linn et al., 1994). IBSE is becoming increasingly popular. Various projects have come up in Europe which are helping and encouraging teachers in STEM education to adopt and follow methodologies which are more interesting and beneficial to students. This is done through online resource sharing, community formation, conferences, and trainings. Some of these projects include Scientix, The Discover the COSMOS initiative, the Volvox project, and PROFILES project - Professional Reflection-oriented Focus on inquiry-based learning and education through science.

To do this, teachers must acquire the competency to apply IBSE in the classroom. This includes determining the level to which IBSE can be used in understanding a topic, at what level and order the students should acquire the knowledge and skills as well as the choice of STEM content by the teacher and its transformation to suit IBSE.

According to research on the implementation of IBSE in science teacher training, the model of IBSE implementation in science teacher training should consist of the following five stages:

- a. Motivation stage: Increasing professional interest and attitudes toward IBSE.
- b. Orientation stage: Acquiring knowledge necessary for IBSE.
- c. Stabilization stage: Solving of simple applied tasks of IBSE application.
- d. Completing stage: Solving of complicated applied tasks of IBSE application.

- e. Integration stage: Solving of teaching problem situation in school practice (new skill is integrated into skill structure) (Trna et al., 2012).

The Ark of Inquiry has tried to walk the teachers through these stages using its online resources and the detailed description of activities.

## METHODOLOGY

### Limitation of Data and Results

While the Ark of Inquiry Project began in 2014 and has a duration of 4 years, the scope of this paper focuses on the implementation phase in Italy, which took place in the Veneto region of Italy. This is due to the fact that our research and analyses took place during internships with the UNESCO Regional Bureau for Science and Culture in Europe (hereafter referred to as UNESCO in-text) in Venice, Italy. The UNESCO is a consortium partner in the Ark of Inquiry Project, responsible for different work packages, including the implementation of the pilot phase in the Veneto region of Italy. However, not all work packages were carried out by the UNESCO, so any other information not directly from this consortium partner has not been included in this report.

Furthermore, our work and analyses focused on teacher feedback from the pilot phase as our internships took place between May and October 2016. The pilot phase survey results from participating teachers were the information available for analysis. This means that some of the recommendations we make in this article are largely pulled from the pilot phase report findings in the Veneto region. Furthermore, the authors of this article helped to prepare the pilot phase report, and some of the suggestions and recommendations may have already been implemented by the UNESCO in subsequent project implementation phases in the late 2016 and early 2017.

This feedback from the Italian teachers in the pilot phase conducted in Veneto, Italy, was qualitative, in the form of annotated responses to interview questions. The coordinators of the project in the Veneto Region of Italy who worked for the project consortium partner, the UNESCO Regional Bureau, conducted these interviews and saved them for analyses on their servers. While this information was requested, it was no longer available and so all of the responses cannot be listed in this article. However, this information was included on the pilot phase report previously mentioned, which was published publicly by the UNESCO Regional Bureau in Venice, Italy, and can be accessed in the references. The authors also cowrote this pilot phase report for the Ark of Inquiry Project in Italy; therefore, the results of this article are focused on this information. Two of the Italian questionnaires, which are the pre- and post- surveys, can be accessed at [https://docs.google.com/forms/d/e/1FAIpQLSfRf\\_XVzezD6A8K90lDOFg6xcGEuKRbhhNCnms\\_2vhZoepf2Q/viewform](https://docs.google.com/forms/d/e/1FAIpQLSfRf_XVzezD6A8K90lDOFg6xcGEuKRbhhNCnms_2vhZoepf2Q/viewform) and [https://docs.google.com/forms/d/e/1FAIpQLSd22fy7\\_Nut2feaHTCPxo8l6xfJkkLvajFzr1SiAFFPVAW6IA/viewform](https://docs.google.com/forms/d/e/1FAIpQLSd22fy7_Nut2feaHTCPxo8l6xfJkkLvajFzr1SiAFFPVAW6IA/viewform), respectively.

One of the limitations of the data collected using the first impressions questionnaire is that most respondents were from India, a developing country where technology is not so widely available in rural and semi-urban areas. The population of respondents we have tapped into for this article come from the people who have access to technology in urban areas. Hence, note that our conclusions do not extend to every population in the whole country. This is true for any survey done in a large country with varied populations and cultures.

### Primary Research

Information, statistics, and quotes from participating teachers about the pilot phase are taken from the Ark of Inquiry pilot phase report, completed in July 2016 (UNESCO Regional Bureau for Science and Culture in Europe, 2016). Additional information about the pilot phase, including pre- and post-surveys for teachers, results from the Ark of Inquiry meetings, trainings, and forums, were collected with permission from the UNESCO Bureau for Science and Culture in Venice, Italy.

The pilot phase for the international Ark of Inquiry Project was conducted in 6 months from September 2015 to March 2016. This involved time for preparation and establishment of agreements with schools who wanted to participate in the Ark of Inquiry Project. There were at least 5 schools in each of the 7 countries participating in the pilot phase and 14 participating teachers.

The first type of information collected for analysis included quantitative and qualitative data from surveys conducted before and after the implementation of the Ark of Inquiry pilot phase in Veneto, Italy. We received survey results and statistics concerning the 14 participating teachers from the coordinators of the Ark of Inquiry Project in the Veneto Region. This survey was in Italian and was created and administered by the coordinators before we joined the team. The Italian version is added in the annexure. We assessed the qualitative answers to survey questions asked of teachers online and the written responses from in-person interviews during focus groups and introductory project meetings.

We also received quantitative data from the Google Forms survey “Ark of Inquiry First Impressions Questionnaire,” which included responses from 30 educators from different countries. The survey and the answers have been included in the Appendix B. This questionnaire was created by the authors of this article in our capacity as interns working on this project for research purposes. The responses were anonymous unless the participant wanted to give their name on the Google Form, and the respondents were not required to answer every question in the form. As a result, please note that, the number of responses to certain questions may not be 30. Their answer for each question was voluntary. This survey was disseminated to these educators over our personal social networking sites, including LinkedIn, Facebook, and E-mail. These data does largely represent students studying education at the postsecondary and graduate level and individuals living and working in urban areas in India and Canada. These survey results were exported into.csv files that were analyzed and interpreted for our own research and for internal review by

the Science Unit, which can be viewed in the appendix and results section below (Appendix B).

### Secondary Research

Some of the results contributing to this article are a consolidation of secondary research done on the topics we thought were primarily important to address the concept of changing the role of a teacher from an instructor to a designer.

## FINDINGS

Large barriers to the Ark of Inquiry’s expansion and success as an online IBSE project include the following:

- A. The consistent and reliable access to technology by students and teachers to take part in the online project.
  - i. Teachers’ capacity to use and manipulate this new technology to make meaningful and relevant scientific learning experiences in the classroom.
  - ii. Teachers’ preparedness and prior training to effectively teach IBSE activities.
- B. The inclusion of all students, more importantly girls, in science, especially when they face stereotypes about their abilities. These are not limited to Italy but are prevalent in various countries.

30 individuals responded to the “Ark of Inquiry First Impressions” online Google Forms questionnaire. 13 of the 30 respondents self-identified as “Teachers,” and 6 of the 30 self-identified as “Students,” whereas 11 of the 30 self-identified as Education researchers, Vice Principals, and Education Developers. Please note that, “Professor” refers to “University Professor,” and “Student,” in this case, refers to university students studying in the field of Education. Note that, not all of the questions were mandatory to complete, so some of the questions have <30 respondents.

Furthermore, there was one individual surveyed each from Denmark, the USA, Canada, and Germany, and 26 individuals surveyed were from India.

### Technology

Many teachers noted that they struggled with the use of technology in the classroom. The scope of technology in this case included the devices that teachers needed to use to connect to the internet and access the Ark of Inquiry platform, as well as the technical skills needed to navigate the online platform. The technical skills were assumed to be basic digital and technological fluency, including being able to open and use a computer, use a word processor, and access the internet effectively. These devices include mobile phones, as well as laptops, desktop computers, and tablets. Each teacher was required to make an Ark of Inquiry platform account and select activities from the platform to implement in their class.

Teachers involved with the pilot phase were enthusiastic about the use of technology. The teachers thought that it was essential that the students were exposed to technology use in the classroom, to prepare them for the future. However, some of the teachers noted that there were issues with the use of

technology in the classroom. The following two main issues concerned:

1. Students' varying access to technology. For example, one teacher noted in their feedback that "for most of the activities, only half of the pupils were able to complete the assignment at home."
2. Teachers' understanding of the technology. While the pilot phase requirements for participation included the ability for teachers to use technology, some of the teachers noted that they needed the assistance of a technology teacher. Some teachers also noted that there was no any internet connection at their school, while others noted a lack of computers available for students.

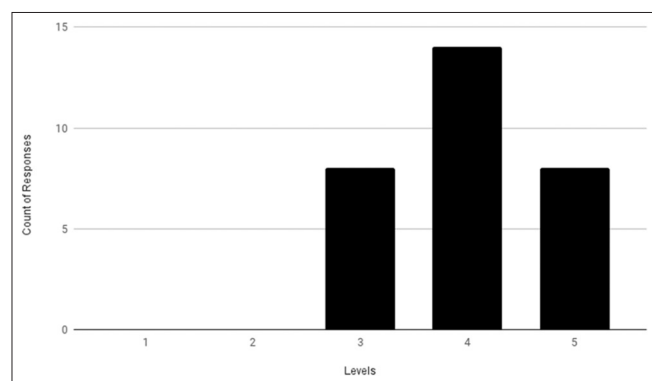
In response to the question "How easy is it to navigate the platform? <http://arkportal.ut.ee/#/>" on the First Impressions Questionnaire, respondents gave answers on a 1–5 scale, 1 being "Too difficult to Navigate and Use," and 5 being "Very Simple to Navigate and Use." 8 of the 30 respondents rated as a 3, 14 out of 30 of the respondents responded as 4, and 8 out of 30 of the respondents rated 5 (Figure 1).

It is interesting to note that almost all of the respondents answered between 3 and 5 on the question "How easy is it to navigate the platform? <http://arkportal.ut.ee/#/?>." Following up to this, 22 of the 30 individuals surveyed answered 'Yes' to the question "Would you use these activities in your educational setting (i.e., classroom, outreach events, and organization)?," however, only 19 of 29 respondents responded "Yes" to "Would you sign up for the platform and become a part of the Ark of Inquiry community?."

It is interesting to note that while all the individuals found the platform easy to navigate, some of the individuals surveyed would use the activities but not join the community. Teachers acknowledged the importance of technology and the role it played in the implementation of most of the activities on the platform. However, they were sceptical about what exactly the students would derive from connecting to the platform online.

## Gender

The Ark of Inquiry consortium members created a Pedagogical Scenario document focused on empowering girls in science



**Figure 1:** Answers to the question "How easy is it to navigate the platform?" on the Ark of Inquiry First Impressions Questionnaire. Responses from 30 individuals were accounted for in this figure

("Empowering Girls in Science," 2016). This document outlined how teachers could create lessons and content that focused on learning with real-world application. This is because teaching with metacognitive pedagogies that allow individuals to reflect on a problem lets students decide their own procedure to solve a complex problem over time. Studies show that this helps to close the gender gap in performance at least in mathematics (Mevarech and Kramarski, 2014). We would also feel confident extending this finding to other STEM courses of the study.

However, teachers involved in the Pilot Phase of the Ark of Inquiry Project in the Veneto region of Italy reported that they did not fully understand how to use the pedagogical scenario document concerning gender inclusion. They reported that they were not sure if girls were actually being effectively included in their STEM classrooms.

We also received answers from the "First Impressions" questionnaire on the question, "Is the (Ark of Inquiry) project/ its activities sensitive to all genders/races/sexes/cultures/ backgrounds? If not, what is a suggestion you could give to make it more inclusive?." For example, one participant noted that they would "need more time to go through and understand this (the project) in depth" if they were to answer the question. This means that they were not sure if the project was inclusive, as they had just begun to look at the project for the first time. More time to look at the project before taking the First Impressions Questionnaire may have yielded more robust responses to this question. However, one individual commented that "I believe in (the) inquiry method of learning. In my perspective it is connected with the culture and background...."

## Teacher Education

The pilot phase results noted that teachers felt that the support extended by the Ark of Inquiry learning community helped them to understand and implement IBSE. In fact, many of the teachers involved with the pilot phase even volunteered to help fellow teachers understand the IBSE procedures of the project.

In the first impression questionnaire, this issue was touched on with the question, "If you were to receive a "teacher's guide" with lessons and activities printed out in a bound book, would you be able/interested to implement the project? (feel free to expand on your selection in the "Other" section)." The respondents gave varied answers. Of the 30 responses, 17 individuals responded that they would be able to implement the project activities and engage with the project. However, 6 of 30 of those surveyed responded that they would be interested in paper copies of the project materials but were unsure if it would be possible to implement the activities in the same way as with the online component.

## DISCUSSION

### Technology

In the pilot phase, we saw examples of some teachers struggling with the use of technology. These issues with technology in



the span of the pilot phase could have been due to a variety of issues outside of the scope of this project, including the at-home use of personal technology and familiarity with technology in an educational setting. This familiarity and acceptance of technology are important to note as the project continues to expand globally; some schools and cultures are more accepting of technology use in the classroom.

It is common to point to age as a predictor of technological fluency. It is a commonly held belief that digital natives or individuals who grew up with technology are more comfortable with using technology. However, in a study done with pre-service teachers who were digital natives, it was shown that digital natives used technology for their own use at a surface level (e.g., for maintaining a social media presence) rather than for personal learning or deeper understanding of the technology itself (Lei, 2014). This means that comfortable with technology does not predict success with technology in the classroom. To turn teachers into designers of effective IBSE learning activities, they must have the skills to leverage technology for learning purposes.

One of the other notes from the first impressions questionnaire was that some students did not have access to technology at home or even consistently at school. For instance, one teacher stated that “for most of the activities, only half of the pupils were able to complete the assignment at home.” If pupils are not able to access the information on the platform on their own, they lose the ability to work on science activities on their own time. This lack of access to technology becomes more of an issue as the project expands internationally. Some communities may have less access to internet connection or technology. Even though 17 of the 30 educators responded that they would be able to implement the project activities and engage with the project if the material was printed out for them, there were 6 of 30 who noted that it may be different than working with the online part of the Ark of Inquiry platform. We also believe that one of the draws of the project is its online community.

We suggest encouraging the use of personal technology such as mobile devices and tablets when school computers or internet are not available. Especially as this project continues to expand globally, its uptake by educators in the classroom may be aided by the “leap-frogging” across the digital divide that has been documented in developing countries (Napoli and Obar, 2013). This term describes the process of skipping traditional desktop computer access to the internet and going straight to the newest mobile technology to access the internet. Leapfrogging has been described as more affordable and accessible than implementing desktop technology solutions. While there are debates about this processes’ merits, mostly concerning mobile device memory, and the responsiveness of web pages on mobile devices (Napoli and Obar, 2013), we believe that encouraging the implementation of more personal mobile devices in the classroom to access the internet may aid the Ark of Inquiry Project’s uptake across different countries as the project expands.

Influence of language used in the technology platform might also lead to the teachers not being comfortable with the technology. The pilot phase teachers were all teachers with Italian as their first language, and the entire project and portal is primarily in English. This problem of language can also be seen with the respondents of the first impressions questionnaire where a majority of them are from India, and English is not their first language. Similar problems will be faced with teachers all around the world where their first language is not English.

## Gender

The confusion over the pedagogical scenario document concerning gender inclusion was in part due to the length of the document and the fact that it was written in English when many of the participating teachers had Italian as their first language. We believe that this kind of problem is quite common when working on large-scale, international education projects; large documents with confusing language can alienate teachers, who already have administrative, classroom, and school community responsibilities to occupy their time and efforts. Lengthy documents may limit teacher’s time to actually design engaging IBSE lessons for their classes. Therefore, information and helpful notes about gender inclusion should be succinct and provide concrete examples for teachers to implement in class.

Feedback from the pilot phase of the project also showed that teachers would find it helpful to have more concrete examples of how to include girls more effectively in STEM activities. This feedback was qualitative, in the form of a verbal discussion between teachers involved with the pilot phase of the Ark of Inquiry in Italy and the coordinators of the project in the Veneto Region of Italy who worked for the project consortium partner, UNESCO. While this information was requested, it is no longer available and so exact counts of responses cannot be given. However, this information was included on the pilot phase report previously mentioned, which was publicly published by the UNESCO Regional Bureau in Venice, Italy, and can be accessed in the references.

The teachers involved in the pilot phase in Italy noted that they would appreciate having short, simple documents with strategies, web resources, and examples to help empower girls in day-to-day science lessons.

As a result of this feedback, a simple infographic was created with research and ideas about how to better include girls in the science classroom, mapped onto the 5 phases of inquiry-based learning designed by Pedaste et al., that is the basis of the Ark of Inquiry’s phases of the inquiry cycle model (2015) (Appendix A, Figure 3). These infographics have been implemented in many of the countries involved with the project in Europe and continue to be translated into partner languages by participating consortium members. As such, more content such as this could be created by the consortium to help teachers design more inclusive lessons to empower girls in STEM fields.

One suggestion from the Gender Guidelines is to use risk-taking women in STEM fields as role models, to create

a representation for girls in the classroom (Appendix A, Figure 3). As mentioned, the incremental theory of intelligence (Dweck, 2007) suggests that intelligence and ability can be acquired through risk-taking. This theory also says that males have been known to be higher risk takers than females, so it is important to motivate female students to take risks and be determined to learn so they will be more likely to learn STEM concepts and innovate in STEM fields. However, this will only be possible when the teachers are clear on how to better include their female students in STEM education; The Ark of Inquiry Project Partner UNESCO produced the Gender Checklist to address this issue (see Appendix A, Figure 3).

One study suggests that during group work in a physics laboratory, it is common for one group member to take control of the experiment, and almost 80% (Holmes and Ido, 2014) of the time, this member is a male student. It can, therefore, be argued that homogeneous groupings of girls in science experiments may be better than mixed-gender groupings, to encourage girls to take more educational risks. Indeed, this is the reason why many science and STEM programs are aimed specifically at girls, to build supportive female relationships in similar STEM fields.

However, this suggestion must be taken with a grain of salt. While it is important to have a supportive group of girls or women in a similar field of study (Shapiro and Sax, 2011), it may also isolate the girls in the STEM classroom and make them less likely to succeed in real-world, mixed-gender STEM work and post-graduate environments. Furthermore, there is evidence showing that girls studying in single-sex schools are not more likely to enter STEM fields than girls who study in coeducational environments (Cherney and Campbell, 2011). Cherney and Campbell's research also showed that girls who completed mathematics test in "stereotype threat" situations (situations where they are confronted with stereotypes about their gender) performed significantly better than girls taking tests in situations that were considered "non-stereotype threat" (2011).

Furthermore, longitudinal research on 37 schools in New Zealand showed that science, mathematics, and english course achievement differences between girls in single-sex and coeducational schools was not significant (Harker, 2000). This shows that exposing girls to stereotypes about their gender and still encouraging them to work in STEM by focusing on their capabilities. It also encourages them to take risks through emulating female role models; the two aforementioned strategies may be successful to apply IBSE in the classroom.

This information also makes the case that all students need to learn to work in groups with high levels of competition if they want to perform in the sciences outside of the school environment. We must recall the pitfalls of the "leaky pipeline," where girls are not aware of the stereotypes that can affect their post-graduate employment prospects. It is also important to note that not all boys are risk-taking, much like all girls are not risk-adverse. If the teacher assigns roles in the group, it may

help to solve this problem; one student must collect the data, one must visualize the data, one must write the hypotheses, etc. By meaningfully assigning these roles, girls will be placed in leadership positions where they are trained to take risks and feel confident in their work.

Instead, and as research suggests, basing STEM learning in real-world problems can help include more girls in the classroom (Sjøberg and Schreiner, 2010). These real-world problems include climate change, disease eradication, medicine, and solving food shortages. Designing IBSE lessons focused on these concepts may also make STEM learning more engaging for all students. We suggest focusing most initial IBSE learning experiences in these real-world STEM applications, as many practical questions can come from students, and result in more authentic inquiry experiences based on their own interests. It may also be easier for teachers to design these experiences since real-world, interesting content helps drive student questioning in the classroom.

### Barriers to International Implementation of Ark of Inquiry

Since most of the sample of educators for primary research using the "first impressions questionnaire" were from a developing country, we would like to focus this section on barriers to international implementation in a developing country context, using India as an example. These findings correlate with the findings of the research based on Britain by the Education Foundation cited in the literature review section (Technology in Education - A System View, 2014).

The followings are the various challenges to the implementation of the Ark of Inquiry.

- Low internet penetration and use of computers
- Prevalence of traditional classrooms and mind-sets
- Lack of resources, including trained teachers
- Prevalence of different cultures and languages
- Sustainability
- Creation of a community.

### Low Internet Penetration and Use of Computers

Although the internet penetration is increasing in developing countries, in India, there is a lack of it in schools with only about 33% of schools having computers with internet (Gupta, 2014). Furthermore, there is no proof of these computers and internet being used in the school for the purpose of learning. For example: "Of the schools I visited, maybe 10% of the computers were working," says Swati Sahni, a consultant who worked for the Indian government on education from 2010 to 2012 (Gupta, 2014).

### Prevalence of traditional classrooms and mind-sets

An analysis of teaching-learning at government schools in India will reveal that the teachers prefer to use the traditional method of teaching in classrooms. Some students study outdated material and rote learning is practised to pass examinations. Convincing school administrators and teachers to experiment with inquiry-based learning may be the most tedious task in this country.



One of the mind-sets prevailing in these countries is the value of teachers in the community. The teachers who were traditionally valued and respected have seen a fall in their respect and value which has led to a lesser number of citizens entering the profession. Even the ones who have entered the profession end up holding other kinds of jobs and earning secondary sources of income rather than focusing on their professional development as a teacher. This has been one of the reasons for resistance from the teaching community toward new pedagogical methods and ICT resources, inspite of it being beneficial to the students.

### *Lack of resources and trained teachers*

While the government is focusing on the distribution of tablets and computers to students for studying, they are forgetting that this needs to be added with internet access and teachers who are trained to teach and help the children in using the technology given to them. For implementation of a project such as the Ark of Inquiry, the teachers need to be trained accordingly.

### *Prevalence of different cultures and languages*

As mentioned above, the culture of education prevalent in India is based on the concept of rote learning and achievements based on marks. This culture needs to be addressed to expose the children to the concept of inquiry-based learning, as this method does not focus on rote memorization.

Furthermore, India has a high representation of females in science and engineering programs of the study (around 65% of total enrolment) but very low representation in the science and engineering workforce (about 12.7%) (Huyer and Halfkin, 2013). This shows that though females engage in STEM education, these females either do not work at all or do not work in a STEM-related work environment, likely due to the aforementioned “leaky pipeline” effect (Blickenstaff, 2005).

Countries such as India, Sri Lanka, Bangladesh, and African countries have different languages within their countries. Hence, the project and activities would need to be translated to the appropriate state language. Translating materials into the local language and having interpreters present may require additional resources and/or reduce the amount of content that can be given in a specified time. Not only translating and training the teachers but also the teachers trained would require continuous support in the form of mentors for proper implementation of the Ark of Inquiry Project.

### *Sustainability*

In most developing countries, projects such as the Ark of Inquiry are implemented initially with funding from donor agencies. However, the question arises on how to sustain the project and expand its impact once the initial funding has ended. Enthusiastic teachers might get excited by the idea initially and try to implement it. However, once the funding ends and the resources dry up, they become frustrated and demotivated Wright C.R (2014). This leads them to resist other innovative and advantageous methodologies in their teaching, and they end up following the traditional methods.

### *Creation of a community*

It is clear from the primary research done that while most teachers are interested in the concept of “Ark of Inquiry,” there is not proof of them being interested in forming a community. Like most projects, the Ark of Inquiry might struggle not only to interest teachers but also to create a community of them. The main struggle is to get the teachers to work together toward a common goal by creating the community. Along with the unwillingness of teachers to work together as a community, barriers like different languages and online but not real-time presence will amplify this barrier as well.

### *Teacher Education*

We believe that consistent teacher education, with a portion carried out online, would be an excellent recommendation for a project such as the Ark of Inquiry. Teachers would be able to access professional development materials and ideas from around the world through their technology devices. Networks have already been put in place to educate teachers during in-person, local Ark of Inquiry workshops (Teachers from learners to thinkers, 2016). These networks were also established through regular Email correspondence with participating teachers during the pilot phase, but a complete E-learning course on IBSE teaching would be a vital asset to this project. We suggest that consortium partners look into developing these online learning courses, to connect with more teachers internationally and to expand the project.

Online professional development courses called Additional Basic Qualification Courses exist in Canada for Canadian educators. Similar concepts and courses could be put in place for teachers who want to become involved with the Ark of Inquiry Project; professional IBSE qualifications could be given through consortium partners to teachers as incentives for joining and participating on the online platform. Some of these consortium partners are education research universities with focuses in STEM and IBSE. Therefore, they already possess the background knowledge and academic content to develop a robust online course; the researchers at these centers and universities involved in the Ark of Inquiry consortium could use their knowledge to build out the content for these online courses.

This idea of “teacher as designer” became, especially, important when, as mentioned, 22 of the 30 individuals surveyed during the first impressions questionnaire answered “Yes” to the question “Would you use these activities in your educational setting (i.e. classroom, outreach events, organization)?;” however, only 19 of 29 respondents responded “Yes” to “Would you sign up for the platform and become a part of the Ark of Inquiry community?.” Please note that, this is one of the situations where only some of the respondents answered the questioned and so there were 29 responses instead of 30. While this disparity may infer that the IBSE activities are popular and valuable to teachers, it also shows that the community may not be as valued by educators. We feel that this needs to change. Teachers should help and learn from each other to understand and implement this new type of IBSE learning and pedagogy.

This is where the role “teachers as designers” is so important. Teachers can design their own classrooms as places of inquiry, but they must also design their own networks of STEM and IBSE education professionals. Designing these networks means that teachers must find like-minded teachers with similar pedagogical interests at the school, community, national, and international level to sustain their passion for this very new and exciting type of teaching pedagogy.

There is no longer room for instructor-led “rote memorization” when it comes to addressing the future innovation potential of Europe. Students must now learn to solve problems based on real-world applications, and IBSE and RRI are a change at the classroom level that cultivates this type of innovative thinking. Therefore, teachers must design and build robust networks of educators who are passionate about this type of technology and learning, thereby supporting themselves as they work to create curious spaces for curious minds. As previously mentioned, they can do this by building robust in-person and online networks of teachers who are passionate about this type of technology and learning. This will support them as they design creative learning spaces. To develop these spaces with correct pedagogical knowledge, they must leverage professional development courses, which we believe would be effectively delivered online by the Ark of Inquiry Project Consortium. The Ark of Inquiry Project could be sustained by these networks, which would make the project sustainable and scalable around the world.

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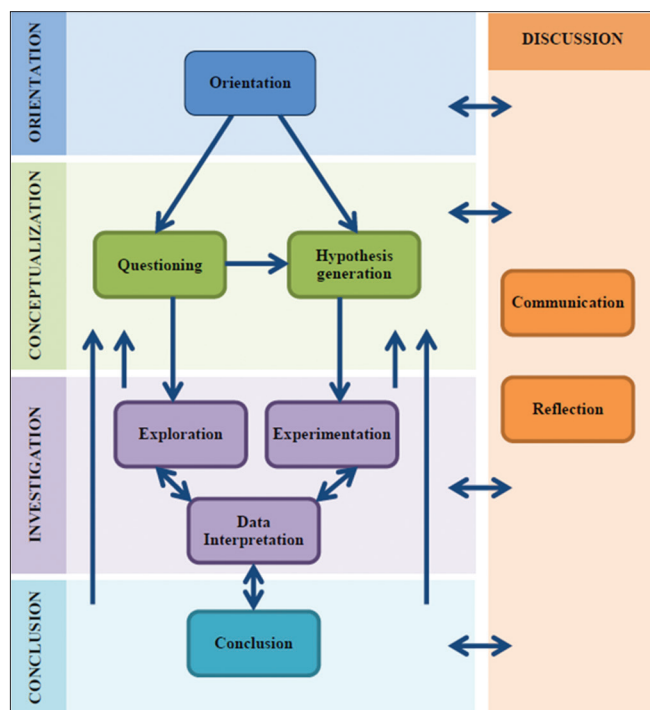
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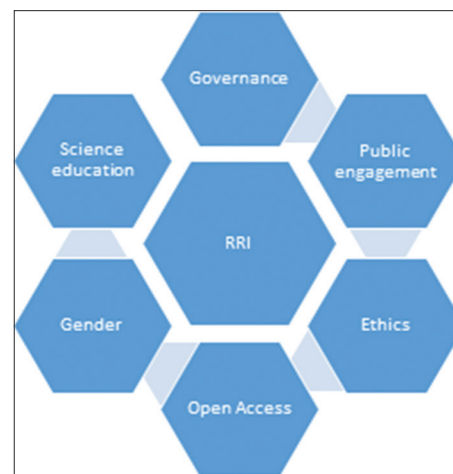
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## APPENDICES

### Appendix A

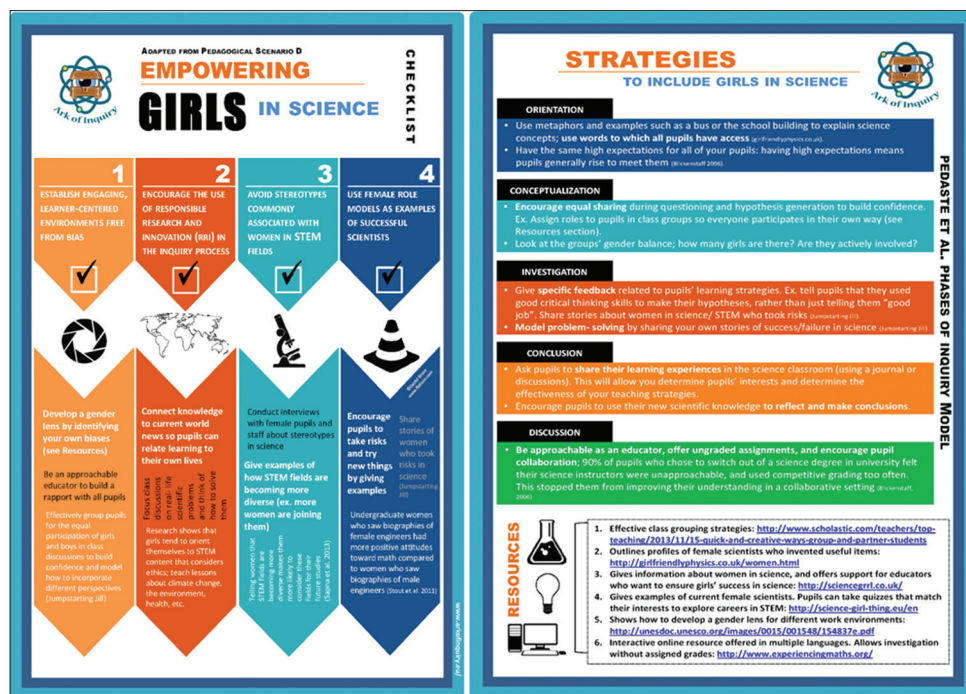


**Figure 1:** Inquiry model as described by Pedaste et al. (2016). This framework was used to build science, technology, engineering, and mathematics inquiry-based science education activities for the Ark of Inquiry Project



**Figure 2:** Responsible research and innovation model as described by European Commission that was used for the Ark of Inquiry Project (European Commission, 2012)





**Figure 3:** Gender guidelines checklist prepared for teachers involved with the Ark of inquiry, to encourage girls in pursuing science, technology, engineering, and mathematics fields (UNESCO Regional Bureau, Venice, 2016)

## Appendix B

### Ark of inquiry first impressions questionnaire content

- What is your profession?  
Student  
Teacher  
Professor  
Researcher  
Other...
- Where are you from?  
Short-answer text  
Section 2 of 5
- How would you rate your first impression of the online platform (out of 5)? <http://arkportal.ut.ee/#/>  
Very poor impression  
1  
2  
3  
4  
5  
Excellent first impression  
Ark of Inquiry Project Logo
- What do you think of the Ark of Inquiry Logo above?  
Does the logo convey the message of the project? Why/why not?  
Short-answer text  
Section 3 of 5
- a) How easy is it to navigate the platform [out of 5]? <http://arkportal.ut.ee/#/>  
Too difficult to navigate and use  
1  
2  
3  
4  
5  
Very simple to navigate and use
- b) Did you understand the purpose of each section on the platform (i.e., teacher's toolbox, activities, community, and my inquiry passport)?  
Short-answer text
- Would you sign up for the platform and become a part of the Ark of inquiry community?  
Yes  
I already did  
No  
Other...
- Would you use these activities in your educational setting (i.e., classroom, outreach events, and organization)?  
Yes  
No
- I have used a similar platform or have been a part of a similar project to Ark of Inquiry (please explain in "other" section).  
Other...  
Section 4 of 5

10. If you work in a setting with limited internet access, how do you think the project could be adapted to suit this setting?  
Short-answer text
11. If you were to receive a “teacher’s guide” with lessons and activities printed out in a bound book, would you be able/interested to implement the project? (feel free to expand on your selection in the “other” section).  
Yes, I would be able to  
No, I would not be able to  
Interested, but unsure if it is possible.  
Not interested  
Other...
12. Is the project/its activities sensitive to all genders/races/sexes/cultures/backgrounds? If not, what is a suggestion you could give to make it more inclusive?  
Short-answer text  
Section 5 of 5
13. How could the Ark of Inquiry Project be expanded beyond its initial goal to only engage European youth?  
Short-answer text
14. Do you think the Ark of Inquiry Project and its materials would be well-received in your country? Please explain why in the “Other” section.  
Yes  
No  
Other...
15. How could the project be modified to appeal to education practices in your country? i.e. at the school level, the teacher level, the pupil level, administration level?